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Information and communication technology in shaping urban low carbon development pathways

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This article examines the emerging nexus of cities, climate change, and information and communication technologies (ICTs) and highlights the importance of ICT innovation-based urban low carbon development pathways in realizing the 1.5 Celsius (C) climate change global policy objective.The first part of the article reviews the three phases of the scientific scholarship on ICTs, climate change, and environmental sustainability, while the second part of the article examines ICTs in accelerating urban climate change mitigation toward the goal of a 1.5C world.The third part of the article highlights three lessons learned in terms of accelerating ICT innovation-based urban low carbon development pathways to achieve the 1.5C policy priority. First, ICT-based technology innovation with a net positive sustainability impact requires smart policy design and co-innovation of complementary sustainable (e.g. energy efficient, etc.) technologies.Second, ICT innovation-based low carbon pathways need both 'hard' infrastructural (i.e. urban transport, buildings, and other physical, built environment) as well as 'soft' infrastructural (i.e. urban norms, habits, and behavioral framing) dimensions to realize urban system impacts.Third, ICT innovation-based low carbon pathways need to be more effectively designed and reconfigured with 1.5C as their primary objective with a special focus on urban climate change resilience in the developing world. Otherwise, global socio-economic, environmental, and technology inequalities are likely to worsen.

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Introduction

If you were fortunate enough to have access to electricity in New York city in 1882, it is likely that you got your power from one of the steam-powered engines operated by an electric power company using coal delivered on horse drawn wagons. If you were fortunate to living in Buffalo, New York in the 1880s, you were probably a select group of people whose electricity were generated by a Nikola Tesla-designed hydroelectric power station, a critical infrastructural resource in turning Buffalo and the nearby New York communities into a Silicon Valley-style 19th century industrial hub [1].

Unfortunately, the cheap fossil fuel-based electricity, power grid, and other related resources-based economic model which fueled New York city and state at the start of the 20th century now represent critical barriers to climate change resiliency-based sustainable urban development in the 21st century.

Building on the urbanization [2•], systems [3], and low carbon energy technology and transition [4,5•,6•] literature, this article examines the emerging nexus of cities, climate change, and information and communication technologies (ICTs) and provides a more nuanced scholarly understanding of the important links between ICT innovation-based urban low carbon development pathways and the 1.5C global policy context [7].

The article is divided into three parts. The first part of the article reviews the three phases of the scientific scholarship on ICTs, climate change, and environmental sustainability, while the second part of the article examines ICTs in accelerating urban climate change mitigation. The third part of the article highlights three lessons learned in terms of accelerating ICT innovation-based urban low carbon development pathways to achieve the 1.5C policy priority.

Understanding the Links between ICT, climate change, and environmental sustainability

Three important phases can be seen in the research and academic scholarship examining the relationship between ICT innovations and climate change and greenhouse gas (GHG) emissions [8].

In the first phase of the ICT and global environment scholarship, the focus was on understanding the first-order effects like the amount of energy consumed by or greenhouse gas (GHG) emissions produced by ICT

hardware and the emerging relationship between ICT, Internet, and the global environment. In this first phase, there were not enough data and analyses in which to adequately conceptualize the relationship between Internet and related information technologies and the global environmental issues [9•,10].

In the second phase of the ICT and global environment scholarship, the focus shifted to understanding the second-order effects focusing on the sustainability impacts of greater ICT use and application (e.g. energy reductions that can be achieved by greater use of ICT in transportation) and the third-order effects of the ICT impact on the broader economic system including the so-called rebound effects (e.g. ICT might lower the cost of transportation service but this would entail more and additional public consumption of that service due to decreased cost) [11••].

Of the 10 most important scientific studies examining the relationship between ICT and GHG emissions in a 2010 scientific review, six studies showed a clear and strong link between ICT use and GHG emission reductions while four studies showed a conclusive but a more ambiguous link between ICT use and GHG emissions reductions, depending on data and future certainties. Most notably, all studies examined in the 2010 scientific review except for one demonstrated a net GHG emissions-reducing potential of ICT [12].

The third phase of the ICT and global environment scholarship focus less on understanding the direct impact of ICTs on electricity consumption and more on with the rapid use and development of 'smart' devices (i.e. those with embedded computing and wireless communication technologies) and the Internet of Things [13,14] technology trend. Because what we now view as 'computing' is shifting rapidly toward more distributed devices and greater use of data centers, this has added another layer of complexity to researching the relationship between ICT and environmental sustainability concerns [15–17]. Fueled by the trend of computing being embedded in many existing and/or new consumer products (e.g. intelligent personal assistants), even trying to define what 'computing' is or understand the boundaries of ICT as a sector have grown extremely complicated.

A more specific review of the macro-economic ICT-enabling GHG reductions in the urban sector to achieve the 1.5C policy goal will be examined in the next section, including the role ICTs is likely to play in creating an enabling policy and business environment in facilitating smart city innovation [18–21]. Although these ICT-based innovations (i.e. smart logistics, smart grid, etc.) are not necessarily unique to urban areas, the critical sustainability intersection of digital technologies and GHG emission trends is most visible in the context of global cities and the urban environment [22].

Role of ICT in fostering urban low carbon development pathways

Four groups of studies, research reports, and analyses (SMART 2020 study analyzing the direct and indirect GHG emission impacts from the ICT sector, C40 Cities Climate Leadership Group report highlighting the important role cities play in meeting the global climate change challenge, Natural Resources Defense Council & Carbon Disclosure Project research examining the scope of GHG emissions resulting from data centers, and International Energy Agency analysis elaborating the relationship between digitalization and energy systems) provide the scientific foundation of ICT innovation-based low carbon development pathways consistent with the1.5C global policy priority.

In 2008, the Climate Group, in collaboration with the Global e-Sustainability Initiative (GeSI), a global green ICT business and policy network, published the SMART 2020 study [23], which estimated that the direct GHG emissions from the ICT sector was 2 percent (as of 2008) and is projected to increase to 3% of global GHG emissions by the year 2020. However, ICTs have the indirect potential (i.e. second-order and third-order effects of ICT use and application) to help industries, governments, and consumers to achieve a 7.8 tonnes of carbon dioxide equivalent/GDP (GtCO2e) or 15% reduction in emissions savings (which is equivalent to five times ICT's direct carbon footprint) in terms of projected 2020 global emissions.

Some of the key ICT enabled emissions savings with important implications for the urban sector include smart logistics (through greater ICT-enabled efficiency in transport and storage internationally, smart logistics practices might lead to an emissions savings of 1.52 GtCO2e with $441.7 billion in economic benefits by 2020); smart buildings (greater global use and application of smart building technologies might lead to 1.68 GtCO2e with $340.8 billion in economic benefits by 2020); and smart grid (diffusion of smart grid technologies around the world might lead to 2.03 GtCO2e with $120.6 billion in economic benefits by 2020).

In 2014, C40 Cities Climate Leadership Group concluded that cities can contribute significantly to bridging the global emissions gap and are positioned to make meaningful contributions toward more aggressive national targets to reduce emissions. Specifically, urban actions, most notably in the buildings (residential and commercial) and transportation (passenger and freight) could decrease global GHG emissions by 3.7 GtCO2e below what national actions are currently on track to achieve in 2030 and by 8.0 GtCO2e in 2050 [24].

While sectors like buildings, transportation, and ICT are distinct separate sectors, trying to delineating what is a

building or more of an ICT technology in a world of smart cities is getting increasingly difficult [25]. This is particularly the situation in the transportation sector in which autonomous driving vehicles and mobility services could be seen as ICT functions. Moreover, a battery-powered electric vehicle is more like a computer with wheels than a traditional fossil fuel-powered automobile. City governments, ranging from Copenhagen to Addis Ababa, are investing in ICT-based 'smart technologies' (e.g. open data stores, citizen engagement platforms, etc.) to help improve urban governance at lower financial and environmental cost [26].

Because of the rapid use and development of smart devices (phones, computers, and so on), coupled with the emerging Internet of Things platform, the most interesting ICT and sustainability research issue might be on the relationship between GHG emissions and cloud computing and data centers. According to a 2014 Natural Resources Defense Council study [27], data centers in the U.S. consumed an estimated 91 billion kilowatt-hours of electricity, equivalent to the annual output of 34 large (500 MW) coal-fired power plants in 2013, with data center power consumption projected to increase to roughly 140 billion kilowatt-hours annually by 2020, the equivalent annual output of 50 power plants.

At the same time, a 2012 Carbon Disclosure Project study [28] concludes that cloud computing can help companies realize $12.3 billion in energy savings and 85.7 million metric tons of carbon dioxide savings annually by 2020 by transferring the data storage capacity of small and medium sized data centers to larger data centers operating on solar and renewable energy sources, while a 2013 Lawrence Berkeley Laboratory study [29] suggests that if all U.S. business users were able to shift their email, software use and other related computer applications to the cloud, the primary energy footprints of these software applications might be reduced by as much as 87% or 326 Petajoules or enough primary energy to generate the electricity used by the City of Los Angeles each year (23 billion kilowatt-hours).

As a 2017 International Energy Agency report makes it clear [30••], a wide range of digital technologies are transforming the global energy marketplace and the pace of this transformation is likely to intensify in the coming decades. Smart meters and connected devices are expected to link more than 1 billion households and 11 billion smart appliances in interconnected electricity systems by 2040, which would allow homes to alter when and how much they draw electricity from the grid as well as more resilient demand-side responses in the building, industry and transport sectors in the form of $270 billion of avoided new investments in new electricity infrastructure.

Guiding ICT innovation-based low carbon pathways in an age of global climate insecurity

Unless ICT innovation-based low carbon pathways are designed and reconfigured with 1.5C as their primary objective and with urban climate change resilience in the developing world as a special focus, global socio-economic, environmental, and technology inequalities are likely to worsen. Three important levers of change have the potential to guide the ICT innovation-based low carbon pathways toward a more realistic 1.5C climate change scenario.

First, ICT-based climate change innovation and sustainability impact does not exist in a vacuum; it requires smart policy design and co-innovation of micro-grid energy technology [31] to fully realize its sustainability impact potential. In many cases, ICT serve as an indirect enabling technology to support urban sustainability solution rather than function as a direct policy solution.

Case in point: based on an integrated environmental assessment using a distributed object-based modeling environment software, a group of University of Tokyo scientists and researchers [32] concluded that it might be possible to achieve a 50% reduction in CO2 emissions in Tokyo by combining a CO2 tax with a gas turbine topping cycle as a supply-side technology and installing energy conservation and rooftop photovoltaic cells in residential and commercial buildings as a demand-side measure.

Second, ICT innovation-based low carbon pathways can only become policy options if 'hard' infrastructural (i.e. urban transport, buildings, and other physical, built environment) as well as 'soft' infrastructural (i.e. urban norms, habits, and behavioral framing) applications are used [33••]. While ICT's 'hard' infrastructural applications may yield important climate change mitigation and adaptation benefits in the short-term, the "soft" infrastructural applications, particularly in the area of data transparency coupled with innovative policy design, may yield the most important climate change mitigation and adaptation benefits in urban areas.

For instance: enacted in 2009, New York City's Local Law 84 legally obligates the city's largest buildings to report how much energy the respective buildings consume each year and receive a score of the building's relative energy efficiency, as compared to similar buildings. The data nudging such green business behavior might be more effective if the underlying building data were more effectively communicated to the public at large [34].

Third, ICT innovation-based low carbon pathways need to achieve the 1.5C climate change goal with economic efficiency and with social equity. Unless ICT-based 1.5C

solutions can be re-designed and calibrated to meet the triple bottom line sustainability needs of the climate change vulnerable urban population in the developing world, socio-economic, environmental, and technology inequalities are likely to be get worse.

A leading search engine's servers refresh 20 billion pages a day, process over 100 billion search queries a month, provide email for 425 million e-mail users and process 72 hours of video uploaded per minute on a video sharing platform. ICT innovation allows more than one billion users to access the Internet and other online resources and just 0.01% of global energy use makes that happen [35]. Unfortunately, in an increasingly economic unequal world, there may be nothing more unequal than access to energy, ICT, and to online resources.

Most notably, the sub-Saharan African region only consumes 145 terawatt hours of electricity a year, which is equivalent of one incandescent light bulb per person for three hours a day [36], while nearly 600 million people (or about 60% of the population) in sub-Saharan Africa has no access to electricity [37]. In its current form, ICT innovations are geared toward meeting the socio-economic and technological priorities of the economically privileged (in both urban and rural areas).

Beyond 'smart' cities: ICT, climate change, and sustainable urban future

If the future of urban energy in the 1880s was a Nikola Tesla-designed hydroelectric power station in Buffalo, New York, you have to travel to Brooklyn, New York to get a sense of what a climate resilient urban energy community enterprise might look like in 2018. Organized as a benefit corporation (a for profit company which is legally required to take into the public and community interest as part of its business), New York city-based Brooklyn Grid is hard to describe.

While it is most often and easily described as a small energy startup, Brooklyn Grid is a virtual energy co-operative which allows solar-energy producers to sell excess-electricity credits from their systems to buyers in the group. By using block chain technology, Brooklyn Grid's peer-to-peer business model allows its current members to bypass the established electric grid and rely on its own micro-grid for energy generation, transmission, and storage [38]. Brooklyn Grid's members can also use an app to conduct the energy trades through their smart phones.

The technological, economic, and environmental drivers transition from the horse-drawn carriage in the 1880s to the motor vehicle traffic in the early decades of the 21st century have resulted in the global climate change crisis. Technology innovations in block chain, micro-grid, and online finance are not only important economic drivers; they may be even more important factors in ensuring a 1.5C global urban future in 2018 and beyond.

Conflict of interest

None declared.

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